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Investigating the real situation of Greek solar water heating market

J.K. Kaldellis*[,1], K.A. Kavadias, G. Spyropoulos

Department of Mechanical Engineering, Laboratory of Soft Energy Applications and Environmental Protection, TEI Piraeus, P.O. Box 41046, Pontou 58, 16777 Athens, Greece

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Abstract

Solar thermal applications have been acknowledged among the leading alternative solutions endeavouring to face the uncontrollable oil price variations, the gradual depletion of fossil fuel reserves and the chain environmental consequences caused by its excessive usage. Almost 30 years after the initial emergence of the commercial domestic solar water heating system (DSWHS) in the European market, the corresponding technology is qualified as quite mature. On top of this, the European Commission expects that 100,000,000 m^2 of solar collectors are to be installed in Europe by the year 2010 to facilitate durable and environment-friendly heat. In this context, the Greek DSWHSs market is highly developed worldwide, having a great experience in this major energy market segment. The present study is devoted to an extensive evaluation of the local DSWHSs market, including a discerning analysis of its time variation, taking seriously into account the corresponding annual replacement rate. Accordingly, the crucial techno-economic reasons, limiting the DSWHSs penetration in the local heat production market, are summarized and elaborated. Subsequently, the national policy measures—aiming to support the DSWHSs in the course of time—are cited, in comparison with those applied in other European countries. Next, the financial attractiveness of a DSWHS for Greek citizens is examined in the local socio-economic environment. The present work is integrated by reciting the prospects and mustering certain proposals that, if applied, could stimulate the local market. As a general comment, the outlook for penetration of new DSWHSs in the local market is rather grim, as the current techno-economic situation of solar heat cannot compete with oil and natural gas heat production, unless the remarkable social and environmental benefits of solar energy are seriously considered. Hence, the Greek State lacks

* Corresponding author. Tel.: +30-210-5381237; fax: +30-210-5381348.
E-mail address: jkald@teipir.gr (J.K. Kaldellis).
[1] http://www.sealab.gr.

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stimulus to further DSWHSs installations, being strongly in support of the imported natural gas. As a result, the future of domestic solar thermal market and the survival possibilities of the local manufacturers are at stake.

Keywords: Solar thermal market; Hot water production; Payback period; Service life; Utilization factor; Market prospects; Market penetration barriers

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1. Introduction

Solar thermal applications have been acknowledged among the leading alternative solutions endeavouring to face the uncontrollable oil price variations, the gradual depletion of fossil fuel reserves and the chain environmental consequences caused by its excessive usage [1,2]. The first solar thermal systems for water heating were commercially introduced after the first oil crises, in the mid-1970s, when the majority of the present-day companies were initially founded. The unstable international oil market and the resulting high-energy cost afterwards encouraged some pioneer manufactures to establish their activity and expand on producing small domestic solar water heating systems (DSWHSs). Almost 30 years after the initial emergence of the commercial DSWHS in the European

market, the corresponding technology is qualified as quite mature, since more than 15,000,000 m^2 have been installed in the EU member states. On top of this, the European Commission—according to the White Paper [3] on Renewable Energies—expects that 100,000,000 m^2 of solar collectors are to be installed in Europe by the year 2010 to facilitate durable and environment-friendly heat.

In this context, the Greek DSWHSs market is highly developed worldwide, having a great experience in this major thermal market segment [4,5]. More specifically, Greece has been playing a dominant role in the European solar thermal market, since it represents almost the 25% of the cumulated installed solar thermal collector surface in the EU-15 countries [6] by the end of 2002 (Fig. 1). Recent publications [7,8] support that the local market sets an example of a ‘success story’ with several perspectives of further development. On the other hand, according to recent research by the authors [9,10], the Greek market has actually been growing at a slow pace during the last decade and it appears to have reached saturation point (see Fig. 2). This is a question that has given rise to much controversy. On one side, a continuously declining initial investment cost evolution in constant terms along with an improved production quality is reported. On the other side, a sales and interest rate decrease is testified concerning the DSWHS, being in contradiction [11,12] with the thriving dynamic solar market of Germany and Austria (Fig. 3).

In view of this inconsistency, the present study is devoted to an extensive evaluation of the local DSWHSs market, situated in the entire European Union solar market frame. For this purpose, a discerning analysis of the time variation of the local market is initially presented, taking seriously into account the DSWHSs annual replacement rate. Accordingly, the crucial techno-economic reasons, limiting the considerable DSWHSs penetration in the local heat production market, are summarized and elaborated. Subsequently, the national policy measures—aiming to support the DSWHSs in the course

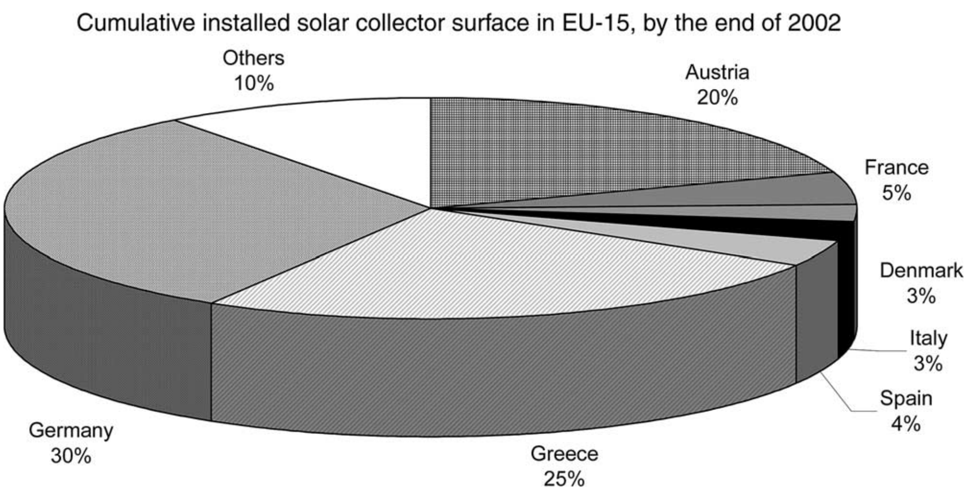

Fig. 1. Market shares of the cumulative installed solar thermal collector surface for each individual EU-15 country member, by the end of 2002.

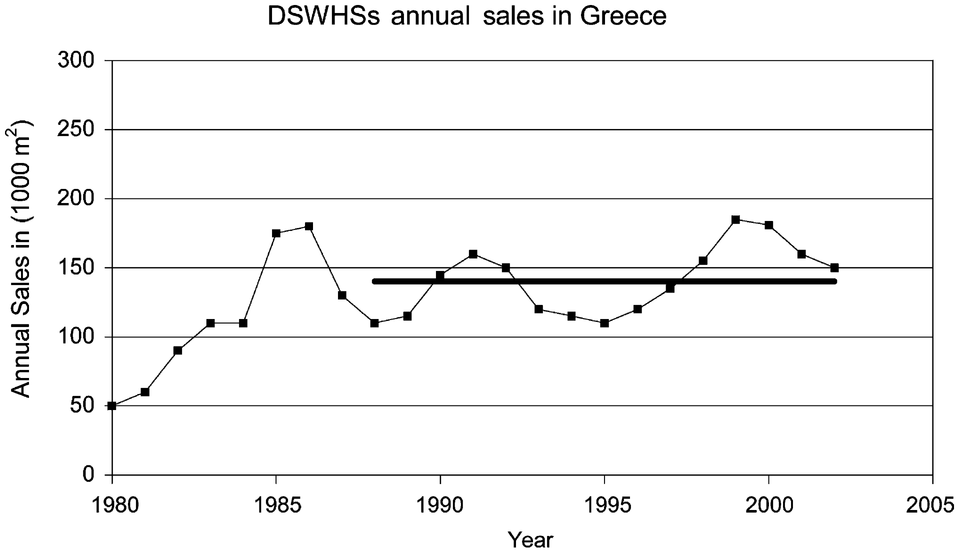

Fig. 2. Time evolution of DSWHSs annual sales in Greece.

of time—are cited, in comparison with those applied in other European countries. Next the financial attractiveness of a DSWHS for Greek citizens is examined in the local socio-economic environment. The present work is integrated by reciting the prospects and mustering certain proposals that, if applied, could stimulate the local market.

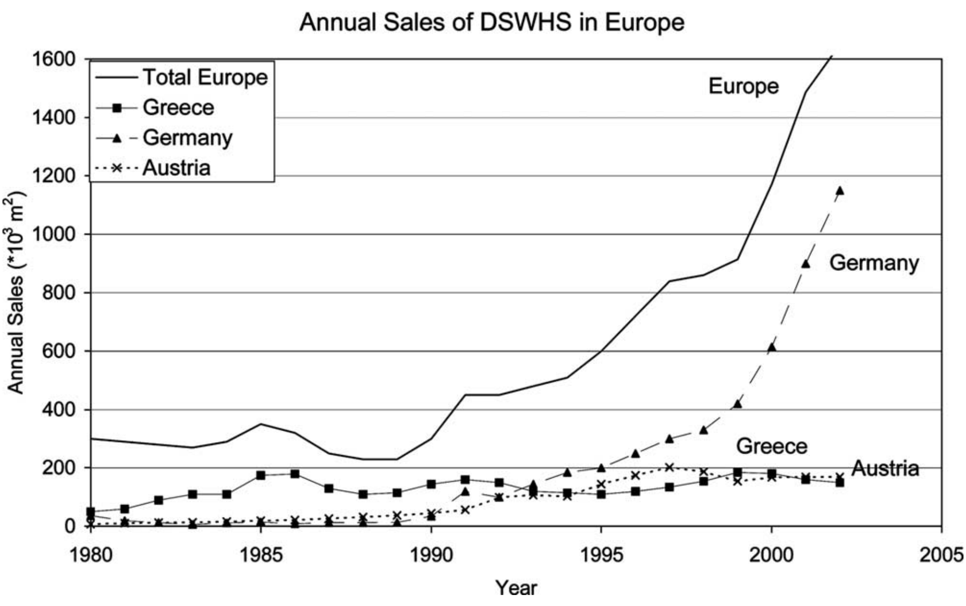

Fig. 3. Comparison of DSWHS European market in the course of time.

2. Historical evolution of Greek solar market (1974–2003)

Greek solar thermal market was established in 1975, after the oil crisis of 1973, when the political situation in Cyprus forced some Cypriots manufacturers to transfer their activities—concerning the DSWHSs sector—in the Greek mainland. During the first decade, the DSWHSs penetration in the local market was progressively rising; motivated by the oil price increase, advertising campaigns and, especially, tax exemptions adopted by the Greek State in support of solar energy applications. As a result, more than 100,000 m^2 of glazed solar collectors were sold through 1983–1984 (see Fig. 2). Due to their immature technology, however, those most primitive systems disappointingly presented major malfunctions during their operation [9,13,14].

In the next 2 years, the local market expanded greatly, approaching the 200,000 m^2 per annum (Fig. 2). A successful state-supported advertising campaign along with the introduction of the value added tax in local economy is the main reasoning behind the DSWHSs sales redoubling. Low interest (soft) loans were also available during this high inflation period, facilitating the purchase of such systems. Since 1987 the local market has oscillated (Figs. 2 and 3) around a gradually decreasing mean value, presenting temporary ups (1991, 1999) and downs (1988, 1995, 2002). The long-term (1988–2002) average value of new installed systems is approximately 140,000 m^2 per annum. Bear in mind that this value does not represent the annual increase of operating solar collectors in Greece, as a remarkable number of DSWHSs regularly comes out of service as a result of ageing.

In fact, Fig. 4 compares the annual DSWHSs collector surface installed all over Greece—according to the data provided by ESIF [4,6]—with the corresponding DSWHSs in operation—based on calculation results carried out by the authors. More specifically,

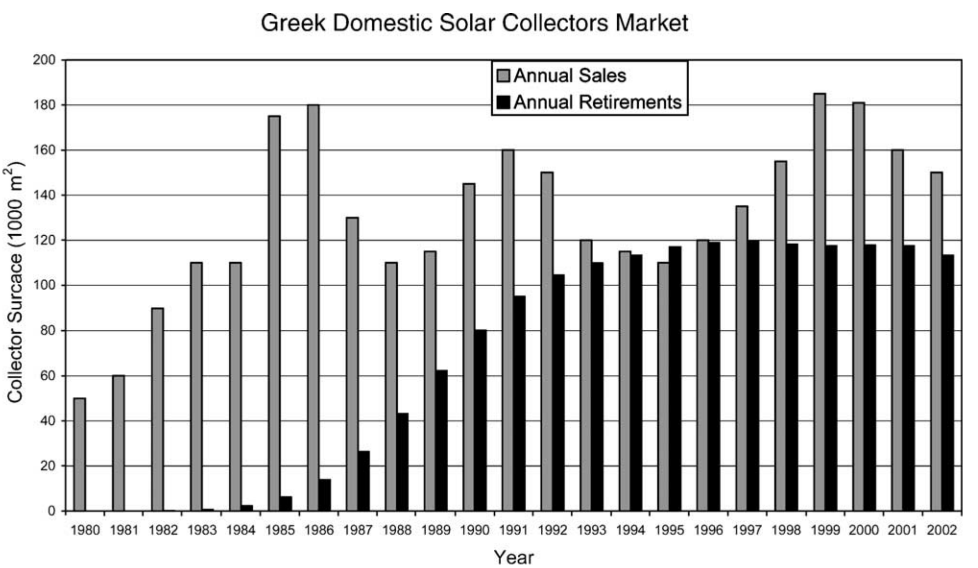

Fig. 4. Comparison between new installed and retired DSWHSs in Greece.

the proposed analysis is based on the following assumptions, validated either by several market surveys or experience:

- The European market experts claim that Greek-made systems are technically simplified, presenting a long-term average service life of about 10 years [15].
- The average service period of DSWHSs time distribution adopted in the present study varies from 7.5 years (±2 years standard deviation) for the early (1980–1985) systems up to 12.5 years (±3 years standard deviation) for the contemporary ones [16].
- A lognormal Gaussian distribution is adopted to describe the possibility of survival of the local market DSWHSs.
- Extended local market survey—carried out during the mid-1990s—found out that more than 1/3 of the solar collector users have faced technical problems with their installation [13], part of which were finally abandoned. During the last decade, however, the quality of the products offered is substantially improving [17], especially after the endorsement of standardization procedure [18] by the leading Greek manufacturers.
- Only 2/3 of the owners of a DSWHS that attests an average service life finally replace their old systems with new ones, taking advantage of the existing installation.

The results of the proposed analysis are quite impressive indicating that during the 1993–1997 period, the actual in service DSWHSs are almost constant (see also Fig. 5). In fact, during 1995, it appears that more DSWHSs are removed than sold in Greece Fig. 4. After 1998, a slight increase of operating systems is encountered, though decelerating during the current decade under the pressure of natural gas penetration in the urban tertiary sector [19].

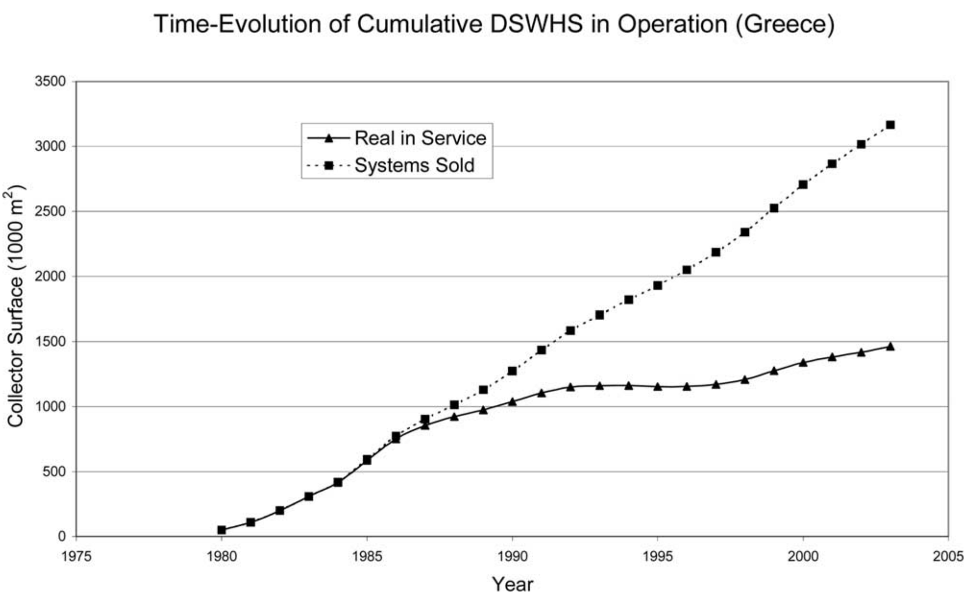

Fig. 5. Comparison between total DSWHS sold and being in operation in Greece.

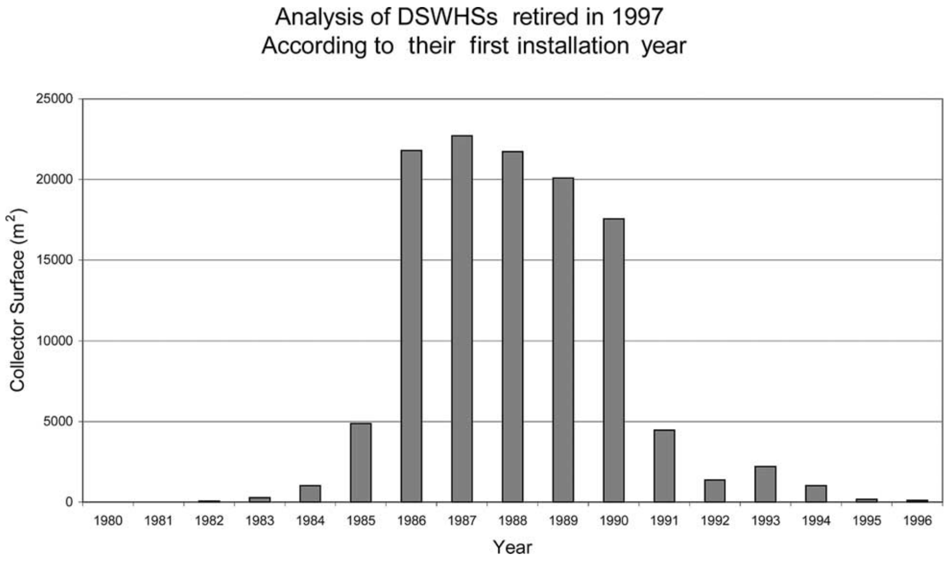

Fig. 6. Time distribution of retried DSWHSs during 1997, on the basis of their first installation year.

More precisely, in Fig. 6, one may, for example, analyse the number of the out of service DSWHSs during 1997 as a function of their first installation year. According to the developed model, a remarkable number of DSWHSs installed during the 1986–1990 (more than 20,000 m^2/year) are removed, after operation of 11–7 years. It is also interesting to mention that after 1997, the number of the first generation (1980–1985) operating DSWHSs is practically zero (i.e. less than 2000 m^2).

As a result, the actual DSWHSs operating in Greece—saving imported oil and preventing emission of several hazardous flue gases—are under the 50% of the numbers introduced either by ESIF [6] or local authorities [16]. More to the point, this time lag of the national policy deviates the country from the European targets for the greenhouse gases emissions restriction [20].

3. DSWHSs major penetration barriers in the local market

The intermitted nature of renewable energy resources, the important disharmony between energy demand and energy production and the short-term supply fluctuations are the major factors that have so far limited the renewable energy applications, including the solar thermal ones. Despite this crucial problem, during the last 30 years, solar energy has proved reliable and economical in cases of hot water production [8,12]. In this context, many researchers claim [4–6] that the European DSWHSs market has remarkably expanded during the recent decade (Fig. 3). After a closer inspection of the available official information, however, one may easily conclude that over 60% of the systems installed in Europe during the last three years were sold in Germany (see Fig. 3), while most other countries currently have considerably lower growth rates or are even

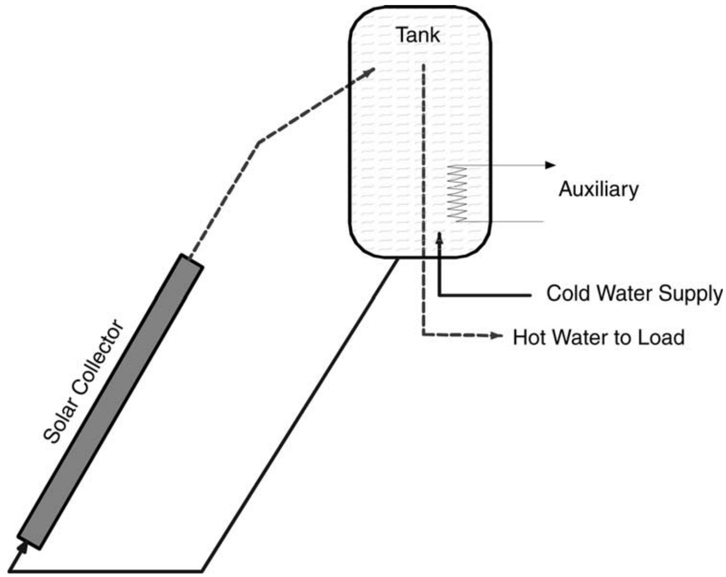

Fig. 7. Typical Greek DSWHS configuration.

stagnating. Unfortunately, this is the case for local market, which—after an impressive solar collector diffusion in the 1980–1994 period—is on the ebb, despite the constantly improving quality and efficiency of the products offered [17].

To get a definite picture of the existing DSWHSs, one should mention that more than 95% of the installed systems—see for example Fig. 7—are based on natural circulation. The average size of the natural circulation systems sold has 2.5 m^2 of collector area and a 150-1 storage tank. The storage tank, horizontal or vertical, is usually positioned above the collectors, while the volume of the storage tank ranges between 120 and 220 1, respectively. All systems use an electrical resistance as a backup-heating source. Only a small minority has an additional heat exchanger connected to a space heating system (usually an oil-fired central heating system). The annual energy output of these systems ranges from 350 to 800 kW h/m^2, although this value greatly depends on the daily and seasonal hot water consumption profile of the user.

Using the available information in the published literature [7,8,13,14] along with extended market survey efforts since 1996 [9,12,17], one may classify the following barriers concerning the decelerated DSWHSs penetration in the local market.

3.1. Limits of available installation locations

Most DSWHSs are positioned on the roof of buildings, since the architectural type of the Mediterranean buildings, i.e. lack of tilted roofs, does not facilitate the integration of solar collectors. The urbanization degree of the major Greek cities considerably limits the available area for solar collectors installation. Besides several ($\approx$30%) Greek households (especially in urban centres) are not under ownership and, therefore, it is not possible for

them to install a DSWHS even if they wish to. Finally, financial constraints have impeded the construction rate of new buildings, while most decision makers in the building sector (architects, house technology planners) are completely unfamiliar with the solar thermal technology.

3.2. First installation difficulties

As most DSWHSs of 'thermosyphon' type seem 'too simple and easy', their installation is often entrusted to unauthorized personnel (untrained plumbers), in anticipation of minimum installation cost. As a result, a remarkable number of DSWHSs either face directions other than true south, or they are significantly shaded by neighbouring buildings, since emphasis is mainly laid on the tilt angle, which does not really affect the annual production [21,22]. In several cases, loose pipe connections, wrong pipe routing, poor insulation and insulation protection or even wrong equipment size may be detected. Installations in rural areas turn out to be even more difficult.

3.3. Technical problems

It is widely accepted that contemporary DSWHSs are of excellent quality, offering increased longevity and remarkable reliability. On the other hand, early systems have habitually presented technical deficiencies, not being sufficiently integrated into building services systems. As an outcome of that faulty technology, DSWHSs had a rather bad reputation, which—although gradually eliminating—is still a suspending factor complicating the introduction of DSWHSs in some households.

To be more accurate, published works mention [13] that more than one-third of the solar collector users in Greece have faced technical problems with their installation. Boiler and pipe damages and leaking have been the most frequent breakdowns, while collector surface damages and thermostat malfunctions/failures are also reported. Other researchers remark that although the technology of solar water heaters has nowadays matured, problems like mismatching of materials with deterioration due to galvanic action along with selection of materials unsuitable for outdoor use or long UV exposure have frequently been faced in the near past [14]. In addition, material problems are regularly associated either with manufacturing process like poor undercoating of steel parts or insufficient application of quality control systems [18].

The appropriate maintenance and operation of the installation plays an equally important role on the unproblematic operation of a DSWHS. People usually disregard the M&O necessity of similar systems, recalling them only in case of malfunction. As a rule, Mediterranean culture adopts the theory that every problem can easily be faced by the local plumbers, although all eminent companies provide maintenance and technical support to local users via authorized personnel.

In an attempt to improve DSWHSs acceptability by consumers, advanced quality assurance standards are applied by several local manufactures, although Greek law does not enforce the compliance of solar thermal products to specific standards. In this direction, as soon as the major manufacturers established the Greek Solar Industry Association (GSIA) in 1978, testing and certification of thermal solar systems became

a prerequisite for being a member of the association. Consequently, the vast majority of companies operating in this sector use certain quality standards. In the country, there is only one laboratory—belonging to a governmental research centre—accredited for collector testing according to EN 45001. Recently (in 2001), the Hellenic Standardization Organization (ELOT) has re-evaluated the above standards. Finally, one should bear in mind that the imported equipment is not subjected to any mandatory testing in order to receive a marketing license.

3.4. Financial reasons

All researchers agree [8,10,23–25] that acquisition cost is among the major barriers discouraging a DSWHS purchase, as they are more expensive than electrical ones, while their long payback period often exceeds the service life of the equipment.

In Greece, purchasing a DSWHS is practically as simple as purchasing an electric water heater. The customer can easily buy such a system through a distributor, an installer or even directly from the manufacturer. A common practice in Greece is selling solar systems directly to users via exhibitions. Hence, the development of solar collector applications in Greece has been following a market-based mechanism.

After an extensive local market survey between 1995 and 2003 by the authors [9,12,17], a small price increase of solar collectors has been encountered—under 13% in current values—being equivalent to a system price decrease by 9% in constant terms. Actually, the buy-cost of a typical system for a single-family house (collector area 2–3.5 m^2 and storage capacity of 120–200 1) has been significantly reduced ($\approx$15% in Euro terms) during the last decade. An additional side effect of the sector's continuous technological progress has been the significant quality improvement realized during the last decade, leading to an increased system technical reliability (lower M&O cost) and hence to a better system economic efficiency.

Another significant reason minimizing the competitive advantages of DSWHSs has been the reduced electricity tariffs. More specifically, electricity retail prices have remained almost constant for the last decade, due to Governmental interventions that kept the tariffs of electricity low, in an attempt to limit the local inflation rate. At this point, it is important to mention that the electricity production had been a state monopoly up to 2001. Similar policy has also been applied in the central heating diesel–oil market by imposing lower taxation.

As a result of this state policy, being in support of fossil fuels, it is quite rational that even the most elementary technologies, like solar water heating, are still immature to compete with conventional energy in market terms. As several authors verify, it is clearly unfair to compare the renewable energy applications with the well-established fossil fuel ones in pure monetary terms [1,23], in view of the social and environmental benefits resulting from the replacement of fossil fuel energy production by sustainable and clean energy resources. In this context, most European societies subsidize the renewable applications to partially introduce external energy cost in the energy decision prospects [3,26].

Summarizing, the ambitious EU goal—set for 2010—promptly necessitates improved political framework conditions for solar thermal energy. At this point, the funding policy

for the solar market development plays a dominant role. All EU countries implement various methods to fund solar technology [4,5]. Subsidies for purchasing solar systems and tax benefits are standard in all countries. In Greece, until recently (2002) the 75% of the system purchase and installation cost was deducted from the individuals' taxable income, leading to a direct first installation cost subsidization ranging from 10 up to 30%. Unfortunately, all these financial incentives were gradually withdrawn, encountering complete lack of solar systems support in the near future. This evolution is a real problem, taking into account the important cost of real estate in the country and the average incomes.

3.5. Public attitude towards renewable energy sources applications

Greek society has a quite different attitude from other central and northern European countries. Hence, the shortage of energy resources, the environmental destruction and the threatening climate catastrophe, although important are not thoroughly influencing Greek citizens [27] in their water heating selection procedure.

On the other hand, due to the national strong individualism, a large number of house owners are positive in installing a DSWHS in an attempt to obtain a high degree of independence. In any case, however, the available family income is a serious factor.

The insufficient public information level [28] on the emergent worldwide energy reserves shortage and the sharp environmental deterioration problems may also be a good explanation for the socio-cultural stance of the local society. Combination of the above reasoning, along with lack of serious and long-term energy-saving incentives from the Greek State and remarkable aesthetic allegation from certain homeowners, present an unambiguous picture of the local citizens attitude towards DSWHSs. Finally, public unawareness in solar thermal applications may also be attributed to the limited number of real-scale large installations in Greece [7,8]. In order to overcome this problem, further demonstration projects are required.

3.6. Insufficient market strategies

Among the major barriers for extensive DSWHSs penetration in the local market is the lack of rational marketing planning and activities. Furthermore, the integration of solar into conventional heating technology, the sales and marketing networks procedure for solar providers and the creation of robust distribution network for all solar thermal equipment is relevant in all European countries The best moment to sell and install solar water heaters is when replacing conventional ones. Regarding the relatively high first installation cost, consumers are prepared to pay the price of a DSWHS if the system is up to standard and technically advanced.

Among the basic drawbacks of the solar marketing policy to date has been the inadequate budget for permanent promotion campaigns, since most manufacturers have been short of funds during the last decade due to sales decrease.

A diffusion barrier observed in Greece—among other European counties, e g Austria—is the indifference of local installers for the new solar technology products. This attitude mainly derives from the absence of systematic technical and sales training of craftspeople

and the deficiency of appropriate information material for consumers consulting. To be fair, some attempts sponsored by the GSIA, ELKEPA (Greek Productivity Centre) and CRES have taken place during the last 30 years, which, however, were occasional and sporadic.

3.7. Lack of state policy in favour of renewable energy sources

According to our opinion, another negative aspect concerning the diffusion of DSWHSs—in common with all the renewable energy sources applications—is the unconcerned standpoint of Greek State. Despite the various E.C. funded operational programmes (for energy 1996–1999, for research and technology and competitiveness (2000–2006)) and the number of laws occasionally including the solar thermal applications subsidization, the state behaviour towards DSWHSs has been groundless and unreliable.

In this context, Greek State has profoundly invested in imported natural gas penetration [19]. Hence, imported natural gas is entering the energy scheme in Greece Huge investments (co-financed by the EU) in the transmission and distribution network are underway. More precisely, Greece has procurement contracts and is constrained to import annually 2.8 billion m^3 of natural gas from Russia and at least 0.51 billion m^3 from Algeria The natural gas is commercialised through the Public Gas Corporation (PGC). The sales of PGC for the year 2000 were 1.9 billion m^3, i.e. the 57% of the purchase quotas, while a large portion of these natural gas imports is used for electricity generation, by the state owned Public Power Corporation (PPC) The PGC strongly promotes natural gas utilization in the building sector, replacing electricity for cooking and oil for heating, in order to cover the remaining 43%. Hence, it is almost sure that the intensive promotion of natural gas should impose a negative impact on the further development of solar thermal applications.

On top of this, the Ministries of Development and Environment/Public Works significantly delay the application of the 'General Building and Energy Code', which has incorporated the energy design of buildings and the energy saving due to renewable applications. The expected new regulations for energy saving in building were not announced, although the corresponding legislative frame was implemented since 1996.

3.8. Recapitulating

According to several researchers, the impressive DSWHSs diffusion in Greece during the 1980–1994 period has basically been following a demand-driven market mechanism Nevertheless, despite this fact most researchers of the sector agree that the local market time evolution was a multi-actor, multi-dimensional and multi-parametric phenomenon. For example, it is almost proved that the extent of solar heat usage does not depend on the amount of sunshine received. Additionally, a number of non-strictly market factors have played major roles, either as driving forces or as barriers. The varying sales growth rate per year demonstrates that the DSWHS market development strongly depends on external factors, like existence of financial support and information campaigns. Finally,

accomplishment of the Altener Project's ambitious targets may be achievable only upon constant and substantial DSWHS support by the local (Greek) government [3,5].

4. Financial evaluation of DSWHS

In order to obtain an unambiguous picture of the DSWHS financial attractiveness in Greece, one should investigate the expected economic behaviour of a similar system in view of any existing state-supported financial incentives.

4.1. Financial incentives

The incentives for the purchase of a DSHWS were first applied in 1978 (i.e. law 814/78), in the form of income tax reduction, representing 75% of the system cost at that time (1978 rates), in case that the purchase cost did not exceed 10% of the citizen's annual income liable to tax. Later, this amount was slightly modified (decreased to $\approx$60%) by the law 1473/84. Considering that the above tax reduction had been expressed in constant numerical values (in local currency), the impact of this incentive faded rather fast due to the high inflation rates of that period (1980–1990); see also Ref. [29]. During this high inflation period, soft loans were also allocated for the purchase of solar systems, covering up to 70% of the system cost.

In 1995, an attempt to support the DSWHS market was made by passing the law 2394/95. According to this law, 75% of the purchase and installation cost of all renewable energy systems is exempted from the individuals' taxable income. Hence, support could obviously originate from legislation and programmes fending for the whole renewable energy sector. Even according to the law 2394/95, the final tax deduction strongly depends on the taxable income of the DSWHS owner.

Considering that the regular income tax rates are, respectively, equal to 15, 30 and 40% (according to the taxable income) and neglecting that any tax return is realized normally 1 year after the DSWHS purchase, the final subsidization amount is between 11 and 30%, (e.g. $\gamma = 0.75 \times 0.40$).

Since January 2004, there are no governmental actions supportive to the DSWHSs' purchase by individuals, as the national energy policy is almost exclusively focused on stimulating the imported natural gas penetration in the tertiary sector.

On the contrary, in an attempt to support the purchase of solar thermal systems, the German government has recently [11] announced a 35% grant increase, aiming to double Germany's solar thermal installations by 2006. In this context, solar panels grants for hot water and space heating are increased from 92 to 125 €/m^2 of collector surface installed. This effort is funded through revenues from the so-called Eco-tax. This continuous and reliable support by the German State is one of the major reasons explaining the flourish situation of the German DSWHS market, despite the limited solar potential of the country. Similar situation also exists in Austria, where on top of the existing grants, the popular use of the thermal solar panels began with the organization of the 'do-it-yourself' groups. This new organization encouraged the further spread of DSWHS in the country.

4.2. DSWHS payback calculations model

The economic viability and attractiveness of a DSWHS could be considered on the basis of the system payback period in comparison with the expected service life of the installation. For this purpose, one should compare the present value of the total investment cost with the corresponding total savings, both expressed as a function of the operational years of the system.

Thus, using previous analysis by the authors [22,29], the present value of the total operational cost of a DSWHS is given as

$$C_n = \mathrm{IC_o}[(1-\gamma) + mh_1] \tag{1}$$

where $\mathrm{IC_o}$ is the turnkey cost of a DSWHS, including the ex-works price of the equipment and the installation cost, i.e. connecting parts, pipe insulation materials, transport, labour for mounting the system, etc.; γ is the state subsidy (if any) expressed as a percentage of the DSWHS turnkey cost; m is the maintenance and operation (M&O) cost coefficient, taking into account the annual repair and maintenance cost, which constitutes expenses for antifreeze, replaced damaged pipes and parts, repaired insulation, glass, paint labour cost and other miscellaneous items. Bear in mind that an annual increase of the cost via the M&O mean-annual-inflation-rate 'g_{m}' is incorporated in the term 'h_1' written as

$$\begin{aligned} h_1 &= \frac{(1+g_{\mathrm{m}})}{(1+i)}\left[1+\left(\frac{1+g_{\mathrm{m}}}{1+i}\right)+\cdots+\left(\frac{1+g_{\mathrm{m}}}{1+i}\right)^{n-1}\right] \\ &= \frac{1+g_{\mathrm{m}}}{g_{\mathrm{m}}-i}\left[\left(\frac{1+g_{\mathrm{m}}}{1+i}\right)^{n}-1\right] \end{aligned} \tag{2}$$

As it is obvious, the 'h_1' term also contemplates the impact of the local market capital cost 'i' (see Fig. 8).

On the other hand, the present value of the total savings 'R_n' over an n-year period due to the thermal energy offered by the solar system is given as

$$R_n = E_{\mathrm{o}}c_{\mathrm{o}}h_2 \tag{3}$$

where E_{o} is the net annual heat output of the installation, assumed constant over the entire operational period of the system (in kW h/year), and c_{o} is the present value of the effective cost coefficient of the substituted—by the DSWHS production—conventional energy (in €/kW h).

Finally, 'h_2' can be written as

$$h_2 = \frac{(1+e)}{(1+i)}\left[1+\left(\frac{1+e}{1+i}\right)+\cdots+\left(\frac{1+e}{1+i}\right)^{n-1}\right] = \frac{1+e}{e-i}\left[\left(\frac{1+e}{1+i}\right)^{n}-1\right] \tag{4}$$

where 'e' is the mean annual rate of the substituted conventional heat-sources market price change (i.e. thermal energy price escalation rate) and 'i' is the above-mentioned local market annual capital cost (see also Fig. 8).

The payback period 'n^*' of the installation can be calculated by comparing the present value of the investment cost with the corresponding total savings, i.e.

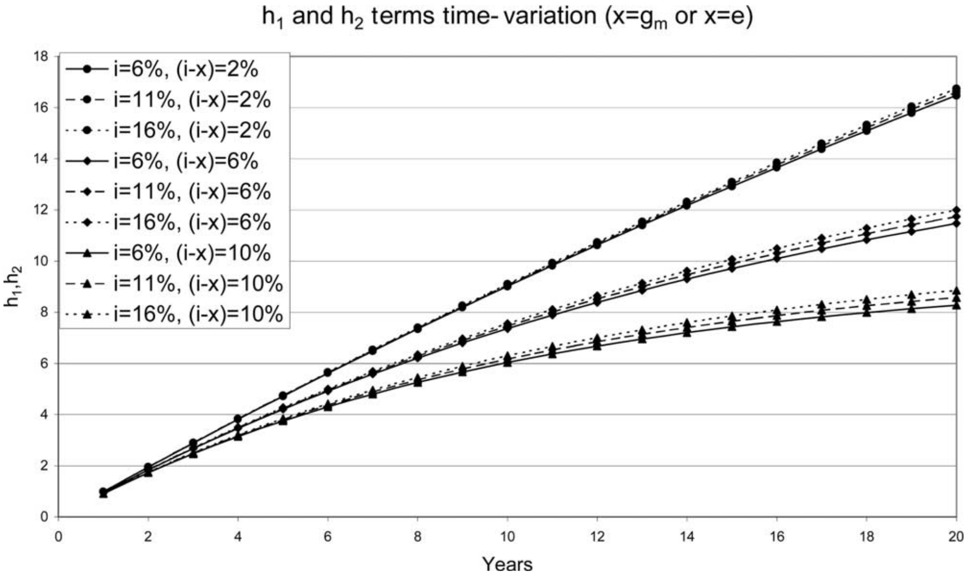

Fig. 8. Time variation of h_1 and h_2 terms of Eqs. (2) and (4).

$$R_n = C_n \text{ when } n = n^* \tag{5}$$

If the predicted payback period is less, than the expected system service one, the investment is characterized as financially viable. Besides, the payback period is in inverse proportion to the financial attractiveness of installation.

For the solution of Eq. (5), in excess of the local market parameters (IC_o, γ, m, h_1, h_2, c_o), one should estimate the annual heat gain of a DSWHS 'E_o', according to Eq. (6), i.e.

$$E_o = \sum_{i=1}^{365} E_i \tag{6}$$

For the estimation of daily solar energy gain 'E_i', one should ponder over the daily hot water consumption pattern per person [30–32] as well as the available solar energy impinging at the selected collector surface [33]. Besides, one cannot ignore the considerable energy heat losses from the hot water storage tank [34], especially during the winter nights for households where all habitants are morning hot water users.

To confront these problems, the authors suggest the following daily solar energy gain calculation model. During the cold season months (e.g. November–April), a rationally sized DSWHS cannot fulfill the daily hot water demand of the consumers (Fig. 9), hence, the system heat gain is determined by the available local solar potential and the system's total efficiency [35,36], including storage tank heat losses, especially for the early morning hot water users. On the other hand, during the hot season periods (e.g. June–September), the available hot water normally exceeds the corresponding demand (Fig. 9), considering the relatively high ambient temperature. Hence, in these cases, the daily heat gain is usually dictated by the load (hot water) profile [30–32,36] of the consumers 'Q_i'.

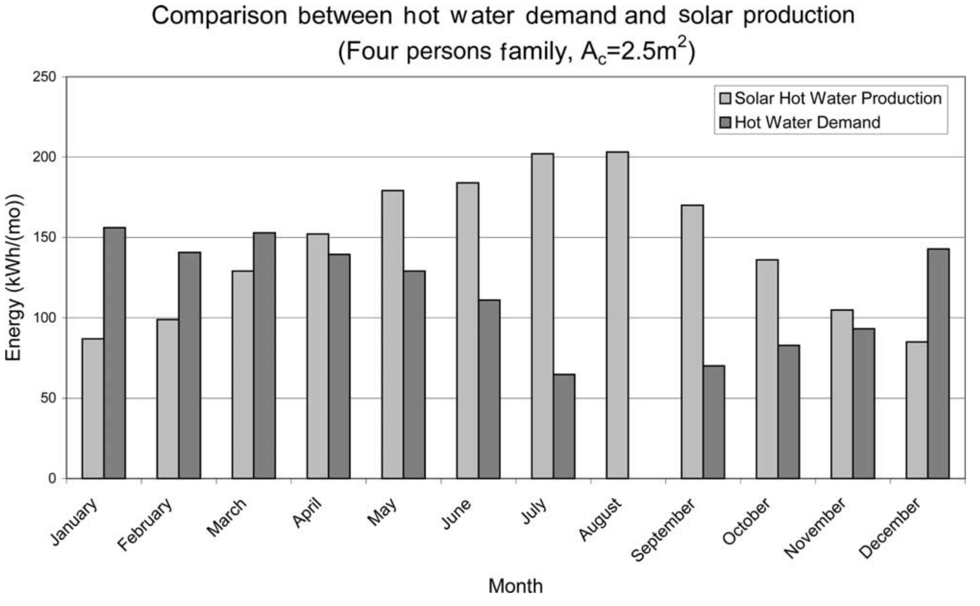

Fig. 9. Comparison between hot water demand and solar hot water production.

Therefore, one may write

$$E_i = \min\{\eta_i H_i A_c; Q_i\} \tag{7}$$

where 'η_i' is the system's daily efficiency and 'H_i' is the corresponding solar radiation at the collector surface.

Recapitulating, the annual solar heat production of the system 'E_o' can be finally calculated on the basis of the hot water consumption daily/seasonal pattern [31,32], the available solar radiation [37,38] and the solar collector surface and efficiency [35,36].

Introducing the system's annual utilization factor 'UF' according to the following equation

$$\mathrm{UF} = \frac{E_o}{H_T A_C} = \sum_{i=1}^{i=365} \min\left\{\bar{\eta}_i \frac{H_i}{H_T}, \frac{Q_i}{H_T A_c}\right\} \tag{8}$$

where 'H_T' is the total available annual solar radiation per square meter collector's surface received locally, Eq. (5) finally reads

$$\frac{\mathrm{IC_o}}{A_c}[(1-\gamma) + m h_1^{(n)}] = c_o H_T \mathrm{UF} h_2^{(n)} \tag{9}$$

As it is obvious from Eq. (9), the payback period of a DSWHS depends on:

- The reduced turnkey price of the installation '$\mathrm{IC_o}/A_c$' (in €/m^2)
- Any state subsidization, expressed as a percentage 'γ' of the initial capital invested
- The annual M&O cost coefficient 'm'

- The present value of the effective cost coefficient 'c_o' of the substituted—by the DSWHS production—conventional energy (in €/kW h)
- The available annual solar energy at the installation location 'H_T', and
- The annual utilization factor of the system. It is important to note that 'UF' describes the portion of the available solar energy finally used by the consumer, in view of the DSWHS efficiency and the daily/seasonal hot water consumption pattern. According to a large number of consumer profiles and solar radiation combinations tested the corresponding UF value normally varies between 25 and 40%.

Finally, the market capital cost 'i', the non-solar heat production cost annual escalation rate 'e' and the system's M&O cost annual inflation rate 'g_m' are also affecting the installation payback period via the 'h_1' and 'h_2' terms (see also Fig. 8).

4.3. Payback calculation results

The above-presented model is applied to three selected Greek regions (i.e. Salonica, Athens and Crete) representing North, Central and South Greek installations. It should be kept in mind that according to a recent study by CRES [16], 62% of the Greek DSWHS in operation are located in central, 27% in Northern 12% in South Greece. The necessary numerical data concerning the parameters of Eq. (9) are given in Table 1. More specifically, the reduced turnkey price of a typical DSWHS properly sized for a four-member family (collector surface 2.5 m^2, hot water storage tank 150–170 l) is approximately equal to 310 €/m^2, while the corresponding effective cost coefficient of the substituted conventional energy is taken equal to 0.080 €/kW h. At this point, it is necessary to clarify that the selected representative consumer covers 30% of his needs (mainly during the winter months when central heating boilers are operating in Greece) using oil, and the rest 70% utilizing an electric heater.

In Fig. 10, one has the opportunity to investigate the calculated payback period of a typical DSWHS operating in one of the three representative Greek territories under zero state subsidization ($\gamma = 0\%$), which is the current situation in the local market, for two

Table 1
Nominal values of the main parameters used in the payback prediction analysis

Parameter	Symbol	Numerical value	Units
Collector surface	A_c	2.5	m^2
DSWHS turnkey reduced cost	IC_o/A_c	310	€/m^2
Effective cost coefficient	c_o	0.080	€/kW h
Reduced annual solar energy	H_T	North Greece 1544, Central Greece 1730, South Greece 1882	kW/h m^2
Annual capital cost	i	9	(%)
Heat annual escalation rate	E	3	(%)
M&O cost coefficient	m	3	(%)
M&O cost annual inflation rate	g_m	2	(%)

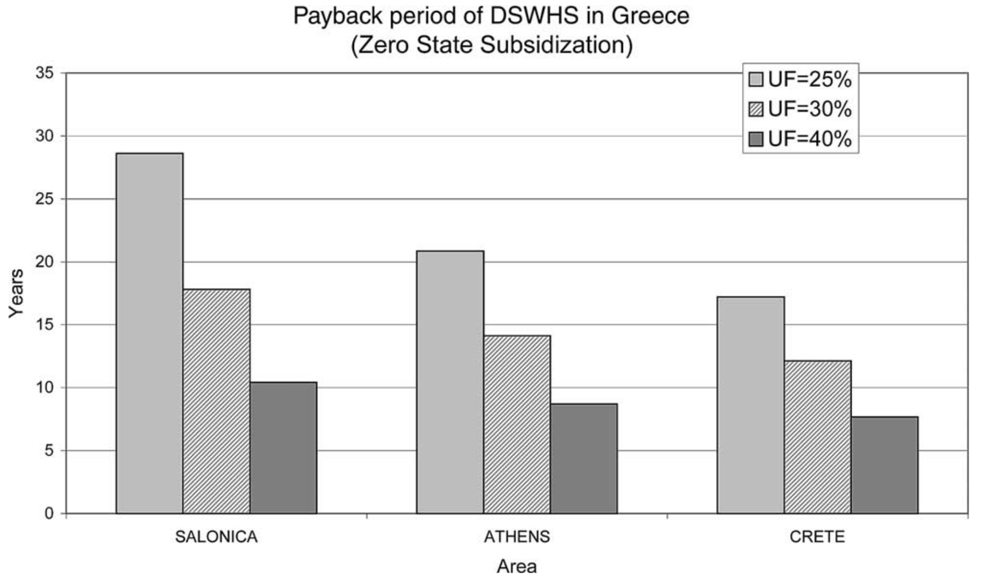

Fig. 10. Payback period of DSWHSs in Greece, without any state subsidization.

extreme UF values, i.e. 25 and 40%, respectively. As it is obvious from the results presented, the expected payback period for the minimum utilization degree scenario in all cases is higher than 17 years, hence almost no DSWHS is financially viable, since the average service period of a contemporary DSWHS is assumed equal to 12.5 years (± 3 years standard deviation). This fact is much more evident for Athens major region-estimated payback equal to 21 years—and for Salonica area—estimated payback equal to 28.6 years. Even at maximum utilization of a DSWHS (i.e. UF=40% or 620–750 kW h/m^2/year), the corresponding investment is marginally viable for North and Central Greece, but in both cases, it cannot be characterized as financially attractive, since the corresponding payback period is 10.4 and 8.7 years, respectively. Recapitulating, only 4% of the DSWHS installed in North Greece are expected to have a service period greater than the estimated payback one for a rational utilization factor (i.e. UF=30%), since the calculated payback period is 17.8 years. The corresponding viability percentage is 29.5% for Central Greece installations and 55% for North Greece ones. In this context, in case of zero state subsidization, there is a very small possibility for an individual to cover his annual hot water needs by using a DSWHS instead of a conventional oil-fired and electrical heater combination.

In an attempt to estimate the minimum subsidization percentage required to stimulate the competitiveness of DSWHSs in the local market, the former utilization factor is re-evaluated under variable state subsidization percentage, i.e. γ ranges from 0 up to 30%. The calculation results, for all three Greek regions are summarized in Fig. 11. If one sets the minimum acceptable payback period of a DSWHS equal to 9.5 years (the 75% of the systems installed should operate more than 9.5 years without major problems), the necessary subsidization percentage for DSWHSs to be installed in North Greece should be

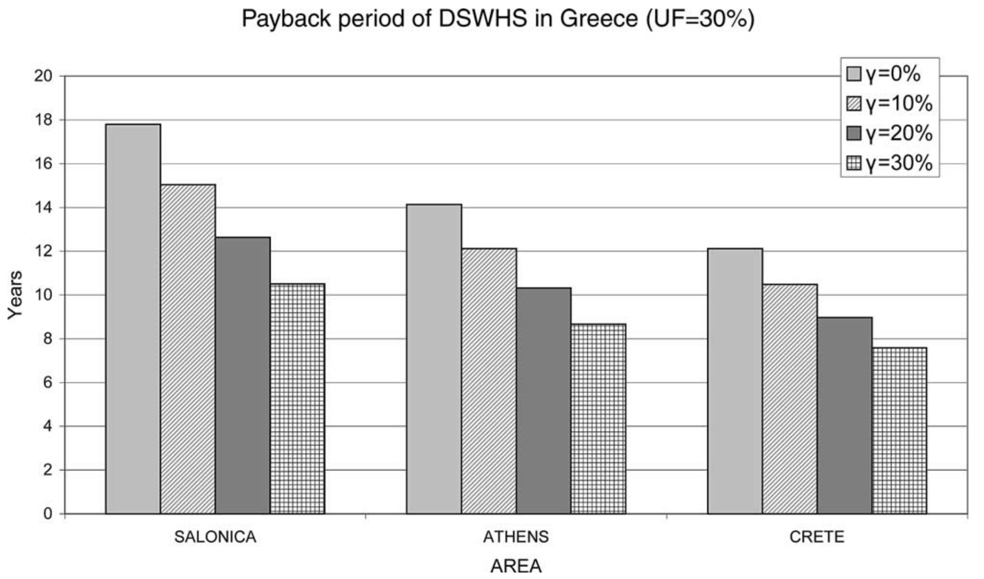

Fig. 11. The Impact of variable state subsidization on the payback period of DSWHS.

equal to 35%, minimum. The corresponding values for Central and South Greece are equal to 25 and 17%. If these subsidization percentage values are not realized, it is almost impossible for an individual to install a DSWHS at his house on the basis of pure financial criteria. This is not a prerequisite for 'green' consumers or other 'self-build' movements.

5. Proposals–prospects

According to the above-presented analysis, the solar market in Greece is currently discouraging; despite the abundant solar radiation and the severe environmental and macroeconomic benefits resulting from solar penetration in the domestic energy balance [1–3,23,26]. On top of this, the real number of fully operated DSWHSs is almost 50% of those installed since 1980, hence the corresponding active collector surface of the operating systems is only 1,500,000 m^2 (or 135 m^2 for every 1000 citizens) in comparison with the 3,100,000 m^2 reported by several institutions [4,6] (see also Fig. 5). This last statement complicates the achievement of the E.U. target of 500 m^2 solar collectors being in service for every 1000 citizens [5] by 2010.

Regarding the financial viability of contemporary DSWHSs, it is almost obvious than—under the current situation—the solar heat cannot compete with oil and natural gas heat production, in pure financial terms. Only after the introduction of the remarkable social and environmental benefits of solar energy in the market competition (e.g. as an initial installation cost subsidization), the DSWHSs may become more cost efficient than the corresponding oil or natural gas based alternatives. The authors strongly support the idea that these 'so-called solar systems grants' are only a small portion of the avoided

social and environmental cost [1–3,23,26]. In fact, there is a common agreement among researchers that the above-avoided cost presently amounts to 50% of the minimal purchase value of a DSWHS, for a 10-year operating solar system. Hence, the abolition by the Greek State of any financial grants regarding the DSWHSs installations is a partial and unreasonable action encouraging the imported natural gas, jeopardizing the future of domestic solar market and staking survival possibilities of the corresponding local manufacturers.

In an attempt to contribute to the local DSWHSs market recovery, some activities—based on the European Commission's White Paper guidelines—are considered necessary. More specifically:

- Special attention should be paid to a firm National Policy supportive of the environment-friendly and domestic abundant renewable sources. In this context, the government should include in the energy market the external costs and benefits of all energy resources utilized.
- Accordingly, progressive marketing strategies should be developed, mostly based on the distribution and sales expansion, along with technical training of installers and craftsmen to facilitate first installation and maintenance.
- On top of this, additional information is required to raise public awareness both on the environmental benefits and the reliability of new systems with a view to face their early ruined reputation. Besides, one should explain the economic advantage of DSWHS in relation to electric heaters.
- Finally, an effort is also necessary to persuade the decision makers of the building sector about the remarkable prospective of solar systems both in hot water and space heating applications.

As a final comment, the outlook for penetration of new DSWHSs in the local market is rather grim under the current techno-economic situation, especially in view of the natural gas introduction in the urban tertiary sector. Only upon efficient accomplishment of all above activities, in conjunction with a rational incorporation of the external cost in the DSWHSs purchase price, there is a reasonable prospect for local solar thermal market recovery. In addition, Greek islands may establish a prosperous market segment, in view of their excessive electricity production cost and the seasonal hot water demand due to summer tourism.

6. Conclusions

The real situation of local DSWHS market is hereby presented, considering not only the annual number of DSWHS sales, but also the current number of active systems in operation. This information is accordingly elaborated in association with the historical evolution of the local solar market with a view to portray the sluggish solar collector market situation during the last decade.

Subsequently, the most important barriers against the DSWHS penetration are demonstrated, including abolition of any financial incentives by the Greek State. In view

of the current techno-economic frame, the financial attractiveness of typical DSWHS applications is investigated for representative Greek territories and under variable utilization degree of the available solar potential. According to the results of the proposed feasibility analysis, solar heat cannot compete with oil and natural gas heat production in pure monetary terms, i.e. excluding social and environmental impacts. Only under rational first installation cost subsidization, DSWHS present a payback period remarkably lower than their operational life.

Finally, several activities are anticipated to stimulate the local solar heating market, including improved marketing policy and widely spread information in an attempt to activate people. The present analysis is integrated by analysing the prospects of the local market in view of the existing techno-economic situation, underlining that only the Greek islands actually remain a prosperous market segment for DSWHSs.

Presumably, the local DSWHSs market might keep on stagnating against the global environment and the national economy. The sole outlet of this disadvantageous situation may be a firm and reasonable state support of solar energy applications, together with the hereby-proposed suggestions. Otherwise, the contribution of local DSWHS on the European Union targets for sustainable and environmental friendly development will remain negligible, despite the abundantly available solar potential of the country.

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